Drop Structures

Flow-Redirection Techniques

DESCRIPTION

Drop structures are low-elevation weirs that span the entire width of the channel. They are designed to spill and direct flow away from an eroding bank, dissipate and redistribute energy and provide grade stabilization. Drop structures are similar to porous weirs; however, because they are not as porous, they create substantially more backwater than porous weirs. *Figure 6-12* (at the end of this technique discussion) shows various applications of drop structures throughout Washington State.

Drop structures are typically constructed with rock or logs, though sheet pile and concrete are also used. Log and rock drop structures have been used extensively in Washington State to stabilize channel grades, to backwater culverts and to provide bank protection (primarily in fish passage and habitat-restoration projects).

APPLICATION

Applications for drop structures include grade control in degrading reaches, flow realignment, fish passage, channel diversity (pool habitat) and energy dissipation. They are most applicable in channels that have slopes of up to about three percent. The Washington Department of Fish and Wildlife has constructed log drop structures for the purposes of reducing channel slope and improving fish passage, especially through culverts.

It is important to determine whether drop structures are the appropriate solution for the particular mechanism of failure and causes of bank erosion in question (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for guidance). Drop structures are commonly used in degrading channels to restore the channel bed to a more stable profile and elevation. They can also act as grade-control structures by preventing a nickpoint from migrating upstream. Drop structures are inappropriate in aggrading reaches. Aggrading reaches will deposit sediment around and over the drop structure, thereby counteracting their intended function. They should also be avoided where there is the potential for an avulsion. See the screening matrices in Chapter 5, *Identify and Select Solutions* for more guidance on determining the applicability of drop structures based on the mechanism of failure and causes of streambank erosion.

Variations

Drop structures are typically constructed in a symmetric, upstream-pointed chevron or arch configuration. Drop structures have also commonly been installed as straight features across the channel, though they tend to flatten the channel cross section and eliminate diversity in the channel. Straight drop structures are, therefore, not recommended from a habitat-diversity perspective. On the other hand, drop structures that are configured in S-patterns or other asymmetrical layouts across the channel can simulate natural shelves and drops on the channel bed, potentially enhancing habitat diversity.

Deformable Drop Structures

Over time, the length (measured from the upstream edge to the downstream edge) of the drop structure may narrow as rocks fall into scoured holes. Eventually, the components of the structure will become more tightly packed together; however, this will not compromise the structure's strength. Structural stability is provided through careful selection and placement of boulders across the channel. Fractured rock is often necessary to lock the structure together. Arches can only be effective across relatively narrow channels, usually less than 20 feet. The expectation is that the arch may eventually break apart, and the boulders will spread out to form a cluster. This is expected to occur gradually as the bank and bed are stabilized by vegetation and debris. The cluster of boulders remains to form a cascade; an outcome similar to that expected for a porous weir rather than a distinct drop structure.

Emergency

Drop structures are not useful in emergency streambank protection. They completely span the stream channel and usually require construction from within the channel, which may not be possible during an emergency situation. However, on smaller channels that are actively degrading or headcutting, rock may be placed as a grade-control measure during emergency conditions to arrest formation or progression of a nickpoint.

EFFECTS

Drop structures increase backwater conditions by raising the effective bed elevation. This commonly induces sediment deposition and increases the water stage upstream of the structure at a variety of flows. Elevated stage may be a concern for channels within flood-regulated jurisdictions. Deposition upstream of a drop structure is particularly common in moderate to high bedload channels. In degrading channels, upstream backwater effects are not as likely due to minimal sediment availability. In these channels, bank erosion and flooding upstream may decrease. However, downstream effects from scour may create a fish passage barrier. Additionally, a fish barrier may result if the upstream-to-downstream difference in water-surface elevation is excessive.

Even with their potential risk of creating fish barriers, an important benefit of drop structures is the habitat they can provide. They create turbulence cover and a diversity of plunge pools, eddies and velocity chutes. They also catch debris, provide aeration and collect and sort gravel in the tailout for spawning habitat. Realigning the thalweg away from a downstream eroding bank will reduce the depth of near-bank pools; however, loss in pool habitat may be compensated by the plunge-pool habitat created by the drop structure.

Depending upon its shape, the structure may affect the channel cross section. Drop structures that are flat and straight across the channel tend to create a channel cross section that is flat and uniform. The pool created in this case is at the base of the structure and spans the entire channel. Drop structures that have a "V" cross section geometry create a thalweg in the pool and generate more diversity. The pool is longer but narrower and may not span the channel.

DESIGN

Conceptual design drawings are shown in *Figure 6-13* and *Figure 6-14*

Dimensions

The width of the drop structure spans the entire bankfull width of the channel. Straight structures are not recommended. Structures configured as a chevron (shaped like a "V") can be symmetrical or asymmetrical, depending upon the thalweg alignment as it approaches the structure and the desired thalweg alignment immediately downstream. Generally, each leg of the "V" will span to the thalweg. Drop structures have been installed in channels up to 400 feet wide. Drop-structure *length*, or the distance between the upstream and downstream ends, is typically designed to be less than 15 feet to accommodate equipment access and to protect the structure's stability.

The upstream water stage, allowable head differential and desired hydraulics dictate the height of the drop structure, measured at the apex of the arch or chevron. If designing multiple drop structures, the height of the structures should be such that the low-flow head differential from one structure to the next is no more than one foot. The head differential criterion is necessary to ensure fish passage and varies based on passage needs of specific species. If designing a single drop structure, the height is normally set at low-flow water stage while maintaining less than one foot of head differential through the structure.

The allowable head differential of one foot must be satisfied at all flows between the low- and high-flow fish-passage design criteria. The low-flow criterion is the two-year, seven-day, low-flow discharge or 95-percent exceedance flow during the migration months for the species of concern. The high-flow criterion is the flow that is not exceeded for more than 10 percent of the time during the months of adult fish passage. The two-year flood flow may be used as the high-flow when stream-discharge data is unavailable. Note that the one-foot head differential applies for passage of adult chinook, coho, sockeye and steelhead. Adult trout (greater than six inches), and pink and chum salmon have an allowable head differential of 0.8 feet. If upstream juvenile fish passage is critical, the drop should not exceed six inches.

Orientation

Drop structures are typically placed in an upstream pointing arch or chevron configuration, or in a straight line across the channel (roughly perpendicular to the flow). If chevron shaped, the alignment of each leg is angled at approximately 45 degrees from the approaching stream flow. If the chevron-shaped drop structure consists of rock, it may eventually evolve into more of a parabolic shape. A chevron-shaped drop structure is hydraulically very similar to a barb; it is basically two barbs that extend from opposite banks toward one another and connect at the thalweg.

When applied in a degraded channel, the height of a drop structure (or a series of drop structures) is set to raise the channel-bed elevation and restore the desired water-surface profile. Care is needed in this case to ensure downstream degradation is not exacerbated. The sediment-storage capacity of a drop structure can be enough to instigate additional degradation downstream. This is especially true if the initial degradation is due to a decrease in sediment supply. Drop-structure spacing is based on the desired channel gradient and angle of flow leaving the structure. The Washington Department of Fish and Wildlife recommends the use of chevron-type drop structures within streams having maximum gradients of three percent and straight-weir-type drop structures in streams having up to five-percent gradients. Chevron weirs concentrate flow energy at the thalweg. Straight weirs spread the energy across the channel and are therefore more efficient at energy dissipation, which allows them to be placed in steeper streams.

Configuration

The drop structure should slope from the banks toward the apex. Generally, the horizontal-to-vertical ratio for this slope should not exceed 5:1. At the bankline, the top of the structure should not exceed the elevation of the channel-forming flow. A notch is often placed in the structure so that boaters and/or fish can pass through during low-flow stages. The length of the legs on a V-shaped structure can vary; and, therefore, the location of the apex varies across the channel. A meandering thalweg and additional channel complexity should be taken into account in positioning the apex. Typically, the apex is located within the center third of the channel. Landward of the bankline, the drop structure should be keyed into the bank to provide scour protection from overbank flow spilling back into the channel. The key will extend from the bankline into the bank at a slope of 1.5:1 to 2:1. A minimum length for a rock drop structure bank key is four times the D_{100} diameter of the header rocks.[1] For sizing of rocks, refer to the technique descriptions in this chapter for *Riprap* and *Porous Weirs*. A minimum length for a log drop structure bank key is a minimum of five feet into the bank.

Large woody debris can be incorporated into the drop structure for added habitat benefit, additional roughness and flow realignment. Such material can be incorporated near the bankline by anchoring a tree trunk with attached rootwad into the drop structure. The tree trunk should run parallel to the bankline. Care must be taken when installing large woody debris since it may also create a constriction and additional backwater. Please refer to Appendix I, *Anchoring and Placement of Large Woody Debris* for further guidance.

It is also important to minimize bank disturbance and vegetation removal during construction. Buried cut-off logs or rocks can be incorporated into the bank key. Buried logs or rocks should be oriented perpendicular to the overbank flows. Revegetating the bank at both keys is necessary for added structural strength and habitat needs. The bank may need to be protected for a short distance upstream and downstream of the key. Large woody debris and/or rock can be placed along the bank as launchable material (see the technique description in this chapter on *Riprap*, for more information about launchable rock). Placement of large woody debris and/or rock at this critical location will help to prevent erosion, which could otherwise result in flanking of the drop structure at high flows.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Placement of drop structures in the channel will fix the bed profile and prompt adjustments in the thalweg alignment. Existing spawning areas may be impacted by new scour patterns that result from these channel modifications. Natural channel evolution, including dynamic erosional and depositional processes, will be reduced. This represents a lost opportunity for future development of habitat complexity resulting from periodic inputs of gravel and woody debris. Habitat losses can be mitigated to some extent by incorporating woody debris into the design of drop structures, as previously mentioned.

The depth of downstream pools adjacent to eroding banks will likely be reduced by redirection of the thalweg away from the eroding bank unless the structure is specifically designed to maintain or create those pools. These near-bank pools provide some of the best types of rearing habitat, especially when there is wood in them and cover from the overhanging bank. Loss of near-bank pool habitat can be mitigated by creating scour pools and placing large woody debris on the downstream side of the drop structure.

The construction of rigid, nondeformable structures such as embedded rock-and-log drop structures requires excavation into the streambed. Construction typically requires significant channel disturbance, which must be mitigated with sediment control and dewatering. Deformable structures are often built on the existing streambed and may therefore not require dewatering. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

Surface turbulence will create hiding cover for juvenile fish. The structure will also provide interstitial hiding areas, particularly near the bank. During high flow, the turbulence may prevent the structure from being very useful as flood refuge for fish. If the required head differential between the low- and high-flow fish-passage design flows is met, fish passage will not be a problem. If there is excess head spilling over the drop structure, adult chum salmon and juvenile salmonids may be prevented from passing upstream.

Drop structures may provide habitat complexity by breaking up a long glide or riffle into different gradients. They also sort and capture spawning-sized gravel in the tailout downstream from the scour holes. Refer to Matrix 3 in Chapter 5 for more detail on the mitigation benefits of this bank treatment.

RISK

Habitat

Drop structures will cause the bed and thalweg to shift and the banks to accrete. Depending upon the channel size, bedload movement and particle size, it may take time for the channel to adjust to this structure. In the adjustment period, spawning areas may scour or accrete, and any eggs or alevins in the bed could be damaged. Relative to other habitat-enhancement options, drop structures tend to provide very uniform habitat features with little diversity if placed in a series.

Infrastructure

The risk to infrastructure situated on the streambanks is relatively low. Drop structures tend to focus stream energy towards the center of the channel and away from the banks. If drop structures are improperly designed and/or constructed, however, the excessive backwater they may create can place upstream property and structures at risk. Drop structures that are constructed too high across the channel or that lack proper sloping toward the channel center can cause increased erosion at the bank key, which may result in flanking of the structure.

Reliability/Uncertainty of Technique

Many rock and log drop structures installed more than 20 years ago continue to function well. If constructed properly and maintained well, it is reasonable to expect that drop structures will serve their designated purpose for many years.

CONSTRUCTION CONSIDERATIONS

Materials Required

Drop structures that are made of rock should use rock that is sound, dense, and free from cracks, seams and other defects that would tend to increase its deterioration from weathering, freezing and thawing, or other natural causes. Angular rock is preferred over rounded rock for its ability to lock tightly together. Rock that resembles native material should be selected when possible.

Drop structures can also be constructed using logs. The type of wood selected may be important if longevity of the bank protection is a concern. Avoid using species that decay rapidly, such as alder or cottonwood. Coniferous species such as cedar, fir and pine are better choices.

Other materials necessary for a drop structure includes filter material (fabric and/or backfill), concrete block and riprap for ballasting and anchoring (for log drop structure), rebar, and large woody debris for mitigation and habitat components. For further discussion of filter materials and large woody debris, refer to Appendix H, *Planting Considerations and Erosion-Control Fabrics* and Appendix I.

Timing Considerations

Drop structures should be constructed during low-flow conditions to minimize instream disturbance. It is typically necessary to work within the stream channel to construct drop structures, which means it may be necessary to dewater the channel. Dewatering can be accomplished using coffer dams to isolate the channel during construction. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations.*

Cost

Drop structures can be a relatively low-cost approach to reducing erosive energy along a streambank. The greatest cost factor is the size of the channel. Drop structures cost approximately $75 to $200 per linear foot. The cost will be determined primarily by the cost of rock available, equipment and operator rates. Rock materials typically range in cost from $25 to $80 per cubic yard. However, dewatering, if required, will greatly increase the cost of the treatment. Additionally, access for large equipment may require that either a temporary access road be constructed, or that specialized equipment such as a spider hoe and tracked dump trucks be used to cross riparian areas for channel access and materials delivery. Refer to Appendix L, *Cost of Techniques* for further discussion of materials costs and construction costs.

MAINTENANCE

Maintenance may include replacement of rocks that shift or are dislodged by extreme flows. Replacement of rocks, logs or vegetation may also be necessary at the bank key-in points after overbank flow events.

MONITORING

Because drop-structure projects involve impacts to both the channel and the banks, the integrity of the structure itself, the channel and bank features and habitat will all need comprehensive monitoring. Monitoring of drop-structure projects should be initiated prior to construction and should include a baseline-conditions survey of the physical channel, its banks and its habitat value. This should include, at a minimum, surveys of five cross sections at intervals equal to the channel width upstream, five cross sections downstream and one cross section at the location of the drop structure. This will allow comparison of modified conditions to preproject conditions. Additionally, monitoring should include detailed as-built surveying and photo documentation from fixed photo points of the project area and the upstream and downstream reaches to allow for evaluation of performance relative to design. Details on development of a monitoring plan are discussed in Appendix J, *Monitoring.*

Monitoring drop structures should include preproject surveys and annual surveys thereafter of key members, and visual assessments of their configuration, dimensions and hydraulic function. A general, qualitative description of the drop structure should also be recorded and may include such observations as the general effect on channel flow characteristics and a visual description of the drop structure. The general integrity of the drop structure should be evaluated, including the identification of any significant settling of header or footer rocks as determined from survey and comparison of photos.

Impacts to the channel and to habitat must be carefully monitored. Channel changes occurring following installation can be documented by reviewing annually any cross sections that were surveyed prior to installation and at the time of completion. Patterns of sediment deposition or scour should be noted. Changes to available habitat also should be documented on a schedule conforming with fish life cycles. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[2] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

REFERENCES

1 U. S. Department of Agriculture, Natural Resources Conservation Service. 2000. Design of Rock Weirs. Technical Notes, Engineering - No. 24. Portland, OR

2 Johnson, D. H., N. Pittman, E. Wilder, J. A. Silver, R. W. Plotnikoff, B. C. Mason, K. K. Jones, P. Roger, T. A. O'Neil and C. Barrett. 2001. Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Washington Department of Fish and Wildlife, Olympia, WA.